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MODELING AND PATH SIMULATION OF AN AUTONOMOUS TOMATO PICKING ROBOT

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ABSTRACT

The objective of the work was to present a robot conceptual design and optimal trajectory of End-effector for open field tomato harvesting. The project was aimed at overcoming the challenge of seasonal labour shortage in tomato harvesting. The harvesting robot was modelled along with a stereo camera, a UR 10 manipulator, a scissor lift, track drive system for robot mobility and a soft robotic gripper for tomato picking. The end – effector was proposed with 3 fingers of silicone rubber material to reduce damaging of the fruit in the process of picking. By dominant gas action, the fingers are bent to decrease the gap of the tip, safeguarding the fruit within the end-effector. In accordance with the farm environment and standard planting mode, the robot configuration was determined, whose operating room could be adjusted vertically to increase the picking range. Path simulation results of the End-effector were obtained for the action of selecting tomatoes and place them within the basket. Future integration with tomato-harvesting robotic systems for real field tests of tomato harvesting ought to enhance the practicability of developing autonomous robotic systems.

***KEY WORDS:** Autonomous, Picking, Robotic Harvester, Soft Gripper & Universal Robot (UR)*

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Original Article

INTRODUCTION

Robotic production is a significant modern trend and upcoming development in the arena of agriculture. Research on the design, assembly and use of agro- robots is another important factor which allows the building of a high - quality production environment for Agro- food products.

Tomato is among the world's largest plants grown under conditions of greenhouse and open field cultivation. Previously, tomatoes were only grown seasonally, now they are grown all year round. India ranks2nd in both and tomato production. China and India are the biggest tomato growing countries.

During the production of a high value crop, harvesting is performed several times. Tomato picking depends mainly on manual picking, which results in low harvesting rates. Moreover, as urbanization accelerates, the costs of picking increase. Thus, it is extremely necessary to develop automatic tomato harvesting robots. A crucial aspect of this development is the design of the End-effector.

In designing robots for agricultural harvest, the research community has shown sustained interest. D.V.K. Samuel developed a hand held tool with twelve picking fingers for open field tomato harvesting. The rate of gadget harvesting was found to be 54.0kg/hr, which is 2-2.7 times more than that of bare hands picking. The percentage of losses during harvest was below one [1]. M Monta used the technologies of fruit identification and used sensor signals to identify the mature tomatoes. The robotic arm was fastened to a lightweight four (4) fingered three jointed End- effector. The central axis has been fitted with a vacuum system. For one tomato, the average time needed was 3 min and 37 s [2]. Tanigaki observed cherry collecting robots. Lasers and Infra-Red (IR) lights have been used to locate the fruit accurately to prevent collision with other fruit, when it is cut deeply by the end effector [3]. Johan developed diverse computerized apple harvesting robots. These robots used a 6 axis industrial grade arm and specific gripper for cutting. The End-effector included a funnel made of silicon and suction cup apparatus. A camera was fixed to recognize, locate, and evaluate the ripeness of the apple. The ordinary image dispensation period was 8 to 10 s. The pickingrate of success was around 80% [4]. Chao Ji used a normalized colour difference threshold algorithm to identify mature tomatoes. A scissor - like end - effector was designed. The success rate was 88.6% for the truss tomato harvest, and the average time to successfully pick a truss tomato was 37.2% [5]. Wang Lili presented a Tomato harvesting robot consisting of an independent 4- wheel steering system, a five DOF manipulator system, a navigation system and a binocular stereo visualization arrangement. For automatic recognition of ripe tomatoes, the Otsu algorithm and the elliptic template method were used, and obstacle avoidance strategies were suggested based on the C - space method. The time taken to recognize ripe tomatoes and picking was around 15 s per tomato, with an achievement rate of around 86 percent [7]. Feng Qingchun reported the design and testing of a new harvesting robot system for cherry tomato. To locate the single fruit and measure the fruit bunch, a dynamic visual servo unit was adopted, and a visual unit laser sensor was aimed on target fruit to detect range information using a dynamic image - based visual servo method. A DENSO VS-6556 operated end – effector was used for stem cutting to approach the bunch stem. Field test showed that it spent 12 sec for picking a bunch of tomatoes with a successful rate of 83% [8]. Fatemah Taqi described the development of a cherry tomato robot harvester. By image sensing, the robot identifies the mature cherry tomatoes using a (pixy) (CMUcam5) camera. Control of robot is conveyed by Arduino Uno microcontroller [9]. Yi-Chich CHIU developed a self-ruling picking robot framework for nursery developed tomatoes. The graphical programming language Lab VIEW ver. 7.1 was utilized to build up the picture preparing and control framework. The normal picking time needed was about 35.96 s/test, with a throughput of 100.1 tomatoes/h [10].

This study presents a conceptual design and path simulation of a robot system for open field tomato harvesting.

METHODOLOGY

Robotic System for Tomato Picking

The robotic system is comprised of a 6 axis robotic arm, machine vision, a picking end-effector, control system and a moving vehicle. The system conceptual design is shown in fig 1. The architecture is modelled using the software Solid Works 2018. The architecture is shown in Figure 2.

Manipulator

A six axis Universal Robot (UR10) arm with 1300 mm as working radiuswas used for manipulation, as shown in Fig 1, 2. It weighs 28.9kg and Pay load is 10kg. Control box size is 475 mm x 423 mm x 268 mm and power required is 24 V 2A in control box, 12 V/24 V 600 mA in tool. Materials used are Aluminium, ABS plastic and PP plastic. The robot can work in a temperature range of 0-50°C. Speed of Base and Shoulder is 120°/sand that of Elbow, Wrist 1, Wrist 2, and

Wrist 3 is 180°/s.

End-Effector

The proposed End-effector is a three-fingered one, which comprises of fingers, pneumatic valve, proximity sensor and base plate. Each finger has a length of 135mm and width of 20mm as in Figure 3. Fingers are made up of silicone rubber with hollow inside, allowing pneumatic action of bending. No damage is caused to the tomatoes while picking as the material used in fabricating fingers is smooth. The fingers are bent by controlling pneumatic activation to decrease the tip opening, securing the picked tomato inside the End-effector. The distance between the robotic arm axis base and fingertip tip is 254 mm.

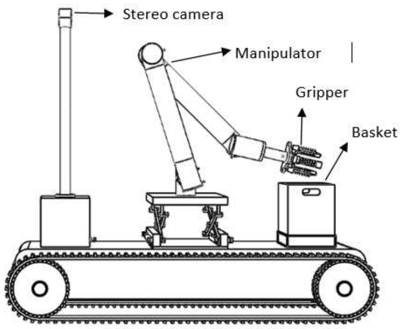

Figure 1: Front View of Robot Modelled in Solid Works.

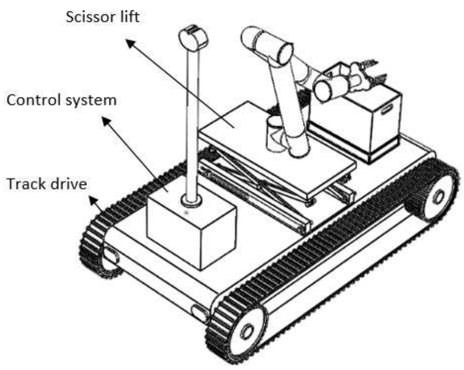

Figure 2: Isometric View of Robot.

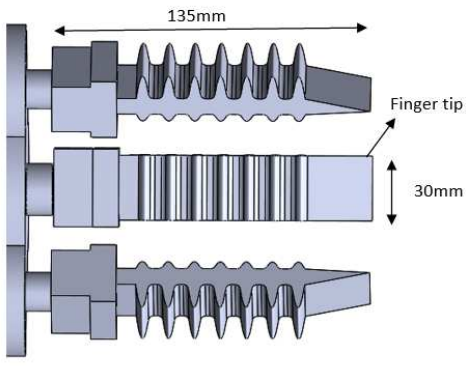

Figure 3: Proposed Gripper Model with Dimensions.

Picking Action Flow

Figure 4 is the picking process flowchart. Firstly, an image is acquired by stereo vision unit to decide, whether the fruit is appropriately mature. If yes, each ripe fruit is considered with the three - dimensional coordinate. The co-ordinate data is then transmitted to the robotic arm that starts picking. First, the gripper is placed in the position, such that the tomato to be picked is at the centre of the three fingers. A proximity sensor is present in the base plate which signals the fruits centre position inside the gripper. Then, the pneumatic action drives the fingers to close, with a pressure less than 2 bars. Once the fruit is held among the fingers, the gripper rotates in clockwise direction by 90 degrees, detaching the fruit from the stem. Finally, placing the fruit in the basket, it completes one harvesting cycle. The same procedure is applied for all ripen enough fruits picking. If the fruit is not enough mature, it moves to the next image automatically.

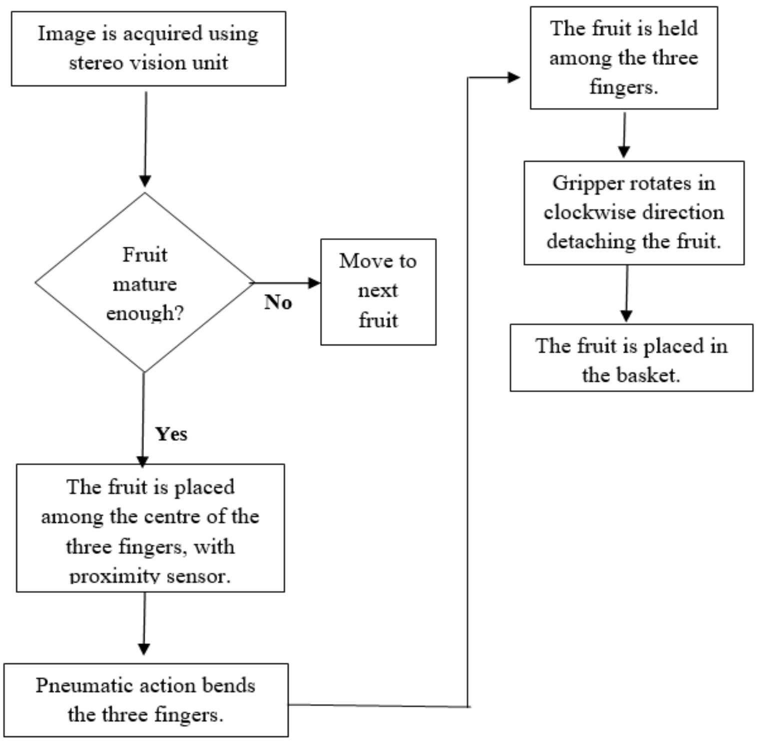

Figure 4: Picking Process Flow of the End-Effector

Joint Parameters of the Manipulator

One of the vital characteristics of universal robot manipulator is that the last 3 joints don't act as synchronic gliding joint. Hence, all of its six joints contribute to its End – effectors transformation and rotational movements. This feature makes the analysis of kinematics compared with other coincidental wrist manipulators. We tend to search and used the foremost valid parameters and measurements of UR10 manipulator that are used for the event of the models, as in Figure 5 and performed path simulation.

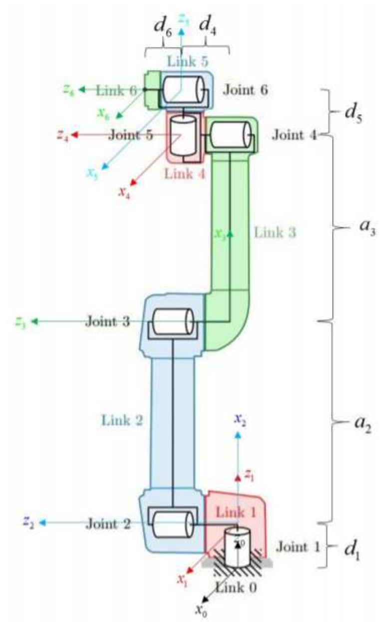

Figure 5: Schematic and Frames Assignment of UR10

Table 1: Denavit-Hartenberg Parameters of Universal Robot Manipulator (UR10)

Joints	θ [rad]	Link Length a_{n-1} [m]	Offset d_n [m]	Link Twist α_{n-1} [rad]
1	0	0	0.1273	π/2
2	0	-0.612	0	0
3	0	-0.5723	0	0
4	0	0	0.163941	π/2
5	0	0	0.1157	-π/2
6	0	0	0.0922	0

Homogeneous Transformation Matrices of Joints

Considering the definition of a robotic arm's transformation matrix, the base - to - end transformation matrix of the manipulator is in the form of

$$^{n-1}T_n = \begin{bmatrix} Cos\theta_n & -Sin\theta_n & 0 & a_{n-1} \\ Sin\theta_n \cos\alpha_{n-1} & Cos\theta_n \cos\alpha_{n-1} & -Sin\alpha_{n-1} & -d_n Sin\alpha_{n-1} \\ Sin\theta_n \sin\alpha_{n-1} & Cos\theta_n \sin\alpha_{n-1} & Cos\alpha_{n-1} & d_n Cos\alpha_{n-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Applying the above formula for all the six joints gave the below results:

$$^{0}T_1 = \begin{bmatrix} Cos0 & -Sin0 & 0 & 0 \\ Sin0\cos 90 & Cos0Cos90 & -Sin90 & -0.1273Sin90 \\ Sin0\sin 90 & Cos0Sin90 & Cos90 & 0.1273Cos90 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & -0.1273 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$${}^{1}T_{2} = \begin{bmatrix} Cos0 & -Sin0 & 0 & -0.612 \\ Sin0\cos 0 & Cos0\cos 0 & -Sin0 & -0Sin0 \\ Sin0\sin 0 & Cos0\sin 0 & Cos0 & 0Cos0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$= \begin{bmatrix} 1 & 0 & 0 & -0.612 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$${}^{2}T_{3} = \begin{bmatrix} Cos0 & -Sin0 & 0 & -0.5723 \\ Sin0\cos 0 & Cos0\cos 0 & -Sin0 & -0Sin0 \\ Sin0\sin 0 & Cos0\sin 0 & Cos0 & 0Cos0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$= \begin{bmatrix} 1 & 0 & 0 & -0.5723 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

$${}^{3}T_{4} = \begin{bmatrix} Cos0 & -Sin0 & 0 & 0 \\ Sin0\cos 90 & Cos0\cos 90 & -Sin90 & -0.163941Sin90 \\ Sin0\sin 90 & Cos0\sin 90 & Cos90 & 0.163941Cos90 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & -0.163941 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{9}$$

$${}^{4}T_{5} = \begin{bmatrix} Cos0 & -Sin0 & 0 & 0 \\ Sin0\cos(-90) & Cos0\cos(-90) & -Sin(-90) & -0.1157Sin(-90) \\ Sin0\sin(-90) & Cos0\sin(-90) & Cos(-90) & 0.1157Cos(-90) \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -0.4480 & 0.894 & 0.10344 \\ 0 & -0.894 & -0.4480 & -0.05184 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11}$$

$${}^{5}T_{6} = \begin{bmatrix} Cos0 & -Sin0 & 0 & 0 \\ Sin0\cos 0 & Cos0\cos 0 & -Sin0 & -0.0922Sin0 \\ Sin0\sin 0 & Cos0\sin 0 & Cos0 & 0.0922Cos0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{12}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0.0922 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad - \tag{13}$$

The above homogeneous matrices were imported in the MATLAB code and simulation results were obtained.

Path Simulation

This simulation system enables the virtual robotic cell to be presented and on a computer screen, robot paths provide a very detailed 3D view [11,12].

Matlab

The End-effector path simulation was developed in MATLAB Software. The code comprised of DH parameters of the universal robot (UR 10), co-ordinates of the Tomato, path and Basket.

Path simulation process in MATLAB is as in below steps:

- **Step-1:** Robotics toolbox is imported in MATLAB.
- **Step-2:** DH parameters of Universal Robot (UR10) are written in the code.
- **Step-3:** The X, Y, Z co-ordinates of Tomato position, path to follow and Basket are given.
- **Step-4:** Forward kinematics keyword is inserted in the code for the given co-ordinates.
- **Step-5**: A MS Excel file is generated with displacement values of the robot motion.
- **Step-6:** the output is plotted showing the path simulation in 3D graph.

Robo Analyzer

Joint angle, joint velocity and joint acceleration for each joint of manipulator motion in picking tomato are obtained in ROBO ANALYZER software.

The process of obtaining joint values is as in below steps:

- Step-1: Manipulator configuration i.e. 6 joints with rotational mechanism is selected.

- Step-2: DH parameters are given as input.
- Step-3: The MS Excel file of displacement values generated using Matlab is given as trajectory file input after finding the velocity and acceleration for each displacement.
- Step-4: Forward kinematics analysis is performed.
- Step-5: The output shows the joint angle in degrees, joint velocity in m/sec and joint acceleration in m/sec^2.

RESULTS AND DISCUSSIONS

Matlab

Path simulation result of the End-effector in picking and placing tomatoes in the basket for five samples in MATLAB is shown in the Fig 6,7,8,9,10.

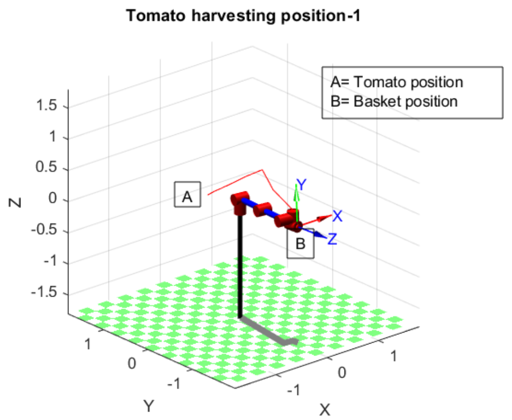

Figure 6: MATLAB Simulation Graph for the Path Simulation of Position-1 to Basket

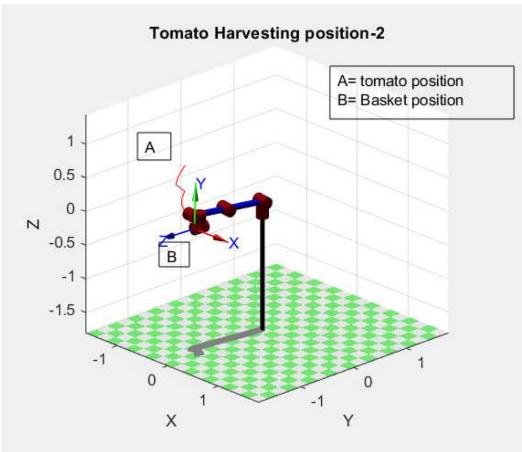

Figure 7: MATLAB Simulation Graph for the Path Simulation of Position-2 to Basket

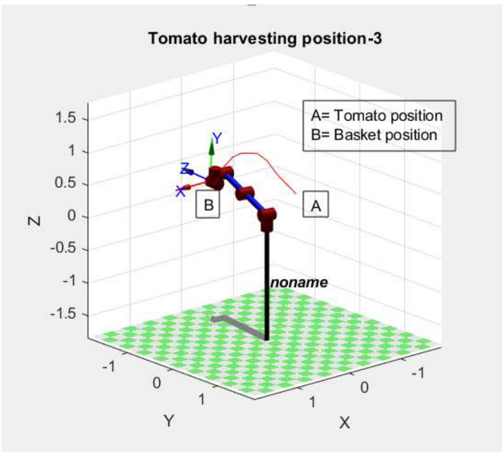

Figure 8: MATLAB Simulation Graph for the Path Simulation of Position-3 to Basket

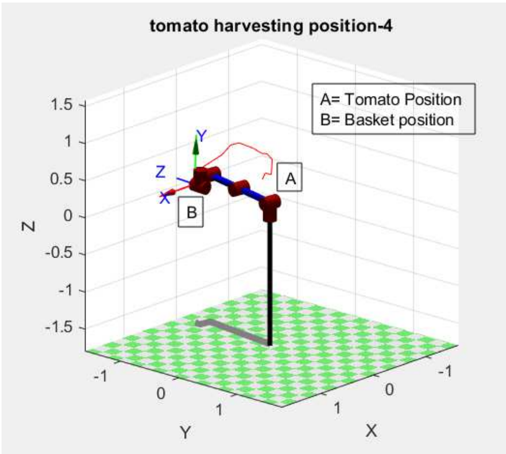

Figure 9: MATLAB Simulation Graph for the Path Simulation of Position-4 to Basket

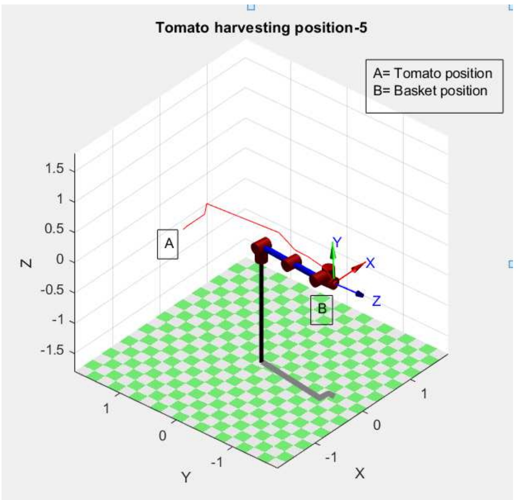

Figure 10: MATLAB Simulation Graph for the Path Simulation of Position-5 to Basket

Robo Analyzer

For manipulator motion joint angle, joint velocity and joint acceleration graphs are plotted using ROBO ANALYSER software.

Joint Angles

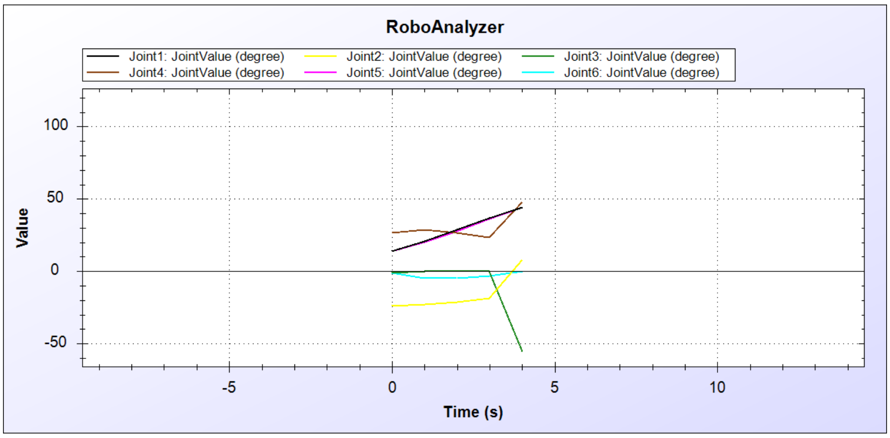

Figure 11: Joint Angles for the Action of Picking Tomato and Placing it in Basket for Position-2.

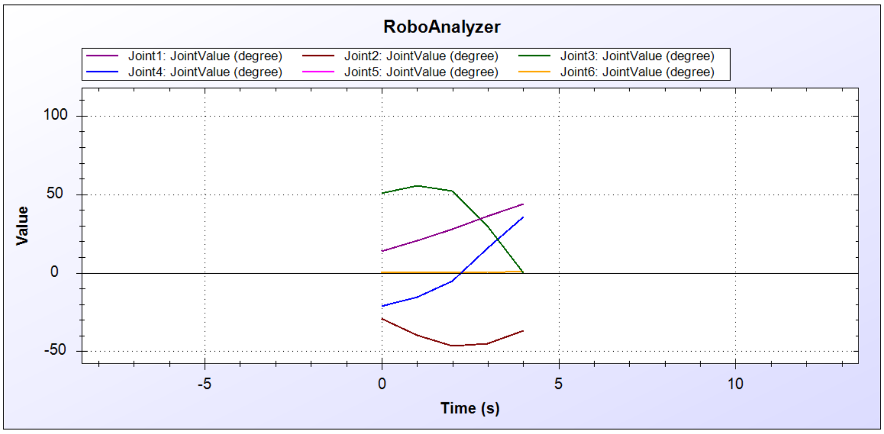

Figure 12: Joint Angles for the Action of Picking Tomato and Placing it in Basket for Position-3

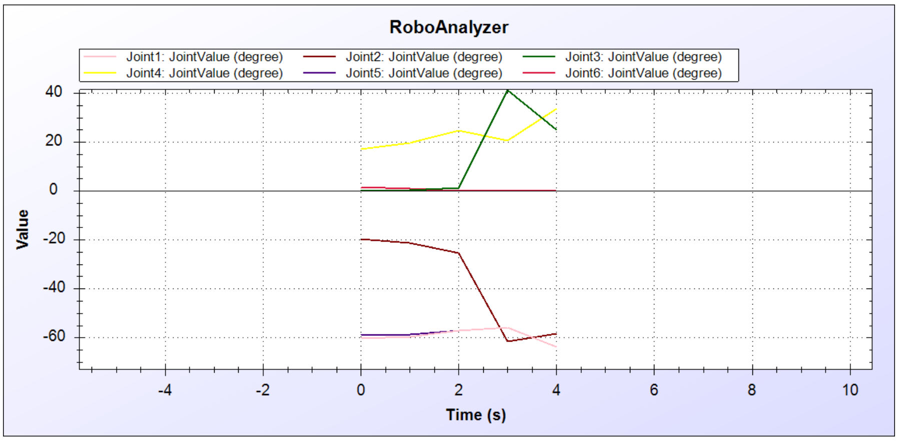

Figure 13: Joint Angles for the Action of Picking Tomato and Placing it in Basket for Position-5

Joint Velocities

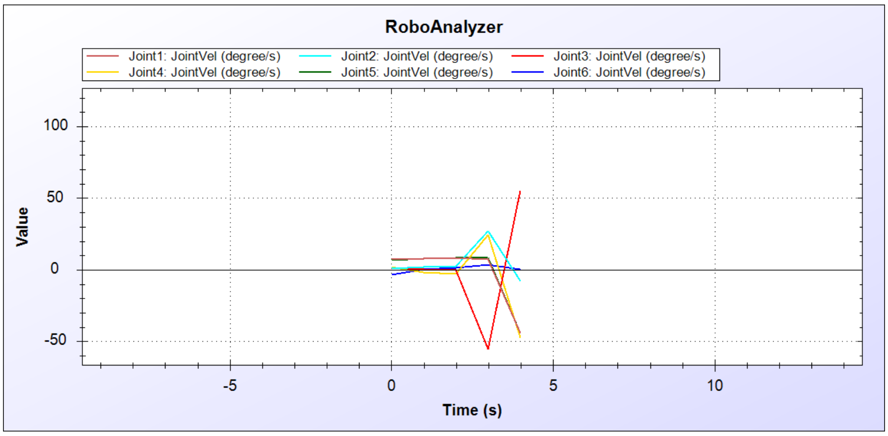

Figure 14: Joint Velocities for the Action of Picking Tomato and Placing it in Basket for Position-2

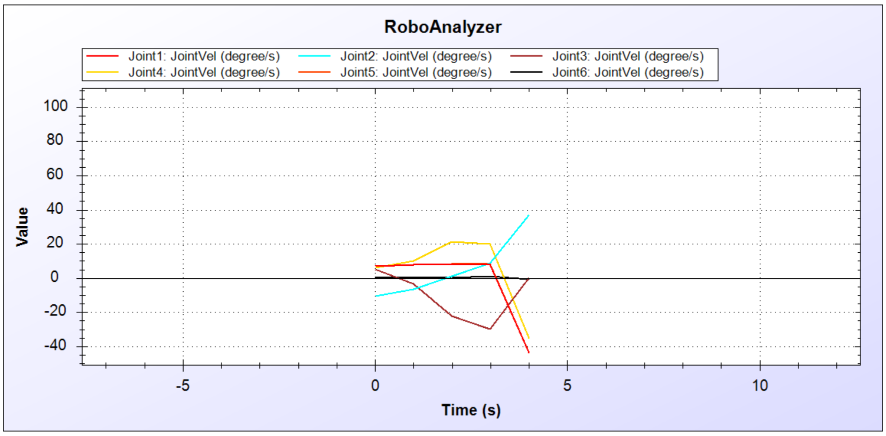

Figure 15: Joint Angles for the Action of Picking Tomato and Placing it in Basket for Position-3

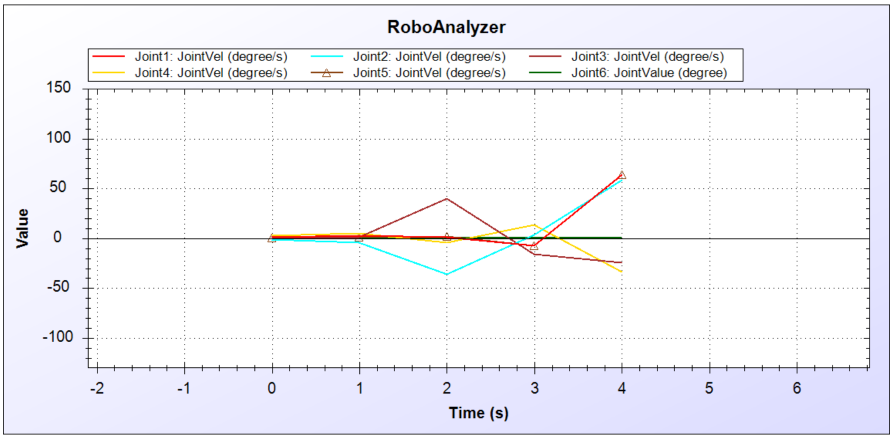

Figure 16: Joint Angles for the Action of Picking Tomato and Placing it in Basket for Position-5

CONCLUSIONS

In this study, a robot design was proposed for harvesting tomatoes in open field, which consisted mainly of a track drive system for mobility of robot, a 6-DOF manipulator, a scissor lift, a stereo vision unit, and a three finger soft robotic gripper. The material proposed to fabricate the gripper was silicone rubber to reduce damaging of tomato while harvesting. The robot configuration was determined to suit with the field environment and standard planting mode, whose operating

space could be adjusted vertically by the scissor lift to increase the harvesting range. Gripper path simulation was created for picking and placing tomatoes in the basket, usingRobo Analyzer software, successfully. The results clearly show the optimal trajectory of gripper and joint values for six rotary joints of the manipulator.

Authors would like to continue to work for the development of mechanical structure, image realization and processing, autonomous tomato identification and gripper motion enhancement.

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